THE NICKEL BULLETIN

A MONTHLY SUMMARY OF CURRENT INFORMATION

OCTOBER, 1957

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ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

GENERAL

Cast Metals Handbook

AMER. FOUNDRYMEN'S SOC.: 'Cast Metals Handbook.' Published by the Society, 1957: 316 pp.

This fourth edition of the Handbook, which has been under revision for the past three years, gives a comprehensive survey of cast materials and casting techniques.

The book is divided into six sections, the scope of which is shown below:

I. *General Information* on the characteristics and properties of cast materials, casting design and methods, pattern making, moulding procedure, specifications for cast metals, mechanical testing of castings, and inspection techniques.

II. *Grey and White Cast Irons.* Methods of manufacture; properties; classification and specifications; heat-treatment; white and chilled iron castings; applications; *bibliography.*

III. *Malleable Cast Iron.* General information; methods of manufacture; properties; pearlitic malleable irons.

IV. *Nodular Cast Iron* (*S.G. Iron*). Production methods; structure; heat-treatment; properties; applications.

V. *Steel Castings.* General information; methods of manufacture; welding technique; specifications for cast steel; applications; *bibliography* (1915–1953).

VI. *Non-Ferrous Alloys.* Information on the composition, treatment, properties and uses of cast materials of the following types: aluminium-, copper-, magnesium-, lead-, nickel-, tin-, titanium- and zinc-base alloys. The chapter on nickel-base casting alloys, by J. S. VANICK, reviews the main types in commercial supply and includes a table giving the nominal composition and properties of the various grades of cast nickel, and of nickel-base alloys available in cast form.

NICKEL

Magnetic Properties of Thin Nickel Films

R. COREN and H. J. JURETSCHKE: 'Hall Effect and Ferromagnetism of Very Thin Nickel Films.' *Jnl. Applied Physics*, 1957, vol. 28, July, pp. 806-9.

Hall-effect measurements were used to determine the two Hall constants and the magnetic properties of nickel films less than 100 Å thick, at room temperature. Some comparisons are made with the corresponding characteristics of bulk nickel.

Welding of Nickel

See abstract on p. 180.

ELECTRODEPOSITION AND OTHER COATING METHODS

Corrosion Testing of Plated Coatings

W. L. PINNER: 'Accelerated Corrosion Tests for the Performance of Plated Coatings.' *Plating*, 1957, vol. 44, July, pp. 763–6.

This is the 4th Progress Report of the A.E.S. Research Project Committee which is investigating accelerated-test methods. The work of the Committee had been planned to 'sift' the methods which have been proposed, and to make intensive study of those which appeared likely to give results correlating with service behaviour.

In 1955 the Committee reported favourably on the acetic-acid salt-spray test and on the Corrodkote method (*ibid.*, vol. 42, pp. 1039–43: *Nickel Bulletin*, 1955, vol. 28, No. 11, p. 182).

The present report gives *detailed instructions for carrying out these two tests.* The recommendations are to be considered tentative, since the Committee is still investigating the possibility of improving both techniques, but results to date have shown good reproducibility, and sufficiently close correlation with service behaviour to warrant their employment in plant control of quality and in evaluating the effect of changes in plating procedure.

(It is of interest, in relation to the views held on the validity of the neutral salt-spray test, to note that attempts to correlate the results of either of the new tests with those obtained by the sodium-chloride-spray method have proved futile and even misleading, due partly to the erratic behaviour of the neutral-spray test and partly to the greater severity of attack imposed by the new tests.)

NON-FERROUS ALLOYS

Order-Disorder Transitions in Nickel-Chromium Alloys

B. W. ROBERTS and R. A. SWALIN: 'Concerning an Order-Disorder Transition in the Ni-Cr System.' *Trans. Amer. Inst. Mining and Metallurgical Engineers*, 1957, vol. 209, pp. 845-6; *T.N.* 392*E*. *Jnl. of Metals*, July, 1957, Sect. II.

The authors briefly summarize the views held by various investigators with regard to the possible

existence of an order-disorder transition in nickel-chromium alloys in the region of 75 at. per cent. nickel. It is suggested that neutron-diffraction techniques provide a useful method of study, since nickel and chromium have considerably different atomic scattering factors in the case of neutrons, and superlattice peaks, if ordering occurs, should therefore be readily discernible. The results of a neutron-diffraction investigation are reported in this note, together with some dilatometric data. The authors make the following comments on their observations:

'The results reported indicate that long-range order of the classic Cu_3Au type is not produced by annealing sequences which result in the observed resistivity and specific-heat anomalies. The lack of diffuse short-range-order maxima suggests that a high degree of short-range order is absent. If long-range order and pronounced short-range order are not considered as the cause of the resistivity change observed near the Ni_3Cr composition, what physical processes remain? Changes in a low degree of short-range order are possible. A precipitation process by ordinary diffusion might cause the resistivity change, but this appears unlikely, since the resistivity was found to begin changing almost immediately upon isothermal annealing at temperatures as low as 479°C. and to reach a maximum in a few hours. An antiferromagnetic transition as a non-diffusion controlled process is to be considered, but no evidence exists for a transition in the vicinity of 540°C. (813°K).'

Diffusion of Other Elements in Nickel

R. A. SWALIN, A. MARTIN and R. OLSON: 'Diffusion of Magnesium, Silicon and Molybdenum in Nickel.'
Trans. Amer. Inst. Mining and Metallurgical Engineers, 1957, vol. 209, pp. 936-9; *T.P.* 4508*E*.
Jnl. of Metals, July 1957, Sect. II.

The paper reports results of a section of an investigation which is being carried out with the aim of gaining a closer understanding of factors governing solute diffusion in close-packed metals. The nickel-base alloys studied contained less than 1 at. per cent. of the added element.

Measurements of diffusion as a function of temperature showed the usual exponential temperature-dependence of D, and the values of the activation energy were found to be close to that for self-diffusion in nickel, with the exception of the value for magnesium, which was rather lower. The results were generally consistent with those reported in an earlier investigation of solute diffusion in nickel: see abstract in *Nickel Bulletin*, 1956, vol. 29, Nos. 8-9, p. 157.

Nickel-Copper Alloy Rivets

SOC. AUTOMOTIVE ENGINEERS: 'Rivets, Solid, Alloy, Corrosion-Resistant.'
A.M.S. Specification 7233; Jan. 7, 1957.

Covers material for solid rivets (which are not to be handpeened during driving), requiring corrosion-resistance at temperatures up to 800°F. (425°C.), where ease of driving and full heads are essential. A shear strength of not less than 49,000 p.s.i. (22 tons per sq. in.) and a Vickers hardness of not more than 140 are specified and requirements are laid down as to condition and quality. The composition range is as follows:

	%
Nickel + Cobalt	63·0–70·0
Cobalt, if determined	1·0 max.
Iron	2·5 max.
Manganese	2·0 max.
Silicon	0·50 max.
Carbon	0·16 max.
Sulphur	0·024 max.
Copper	remainder

'Rivets, Blind, Alloy, Corrosion-Resistant.'
A.M.S. Specification 7234; Jan. 7, 1957.

Covers material intended primarily for two-piece, tubular, blind rivets composed of a pre-assembled hollow rivet on a pull stem, in applications requiring corrosion-resistance at temperatures up to 800°F. (425°C.) and suitable for rapid assembly in blind or open locations where high shear strength is essential. The composition range for the hollow portion is as required in 7233 (see above), with the exception that the carbon and sulphur contents are 0·30 max. and 0·025–0·060 per cent., respectively. The self-plugging stem or mandrel should be of the same composition as the hollow portion, or conform to *A.M.S. Specification* 4730 (nickel-copper alloy wire), and the pull-through stem or mandrel is to be of low-carbon steel. Shear strength, and quality and condition requirements are laid down.

Copper-Alloy Tubes: B.S. Specifications

BRIT. STANDARDS INSTN.: 'Copper and Copper Alloys: Tubes.'
B.S. Schedule 2871:1957. Price 15/-.

This schedule is one of a series covering copper and copper alloys in various wrought forms. Other kindred composite publications now in preparation cover sheet, strip and foil (2870); forgings (2872); wire (2873); rods and sections (2874); and plate (2875).

The present schedule includes copper, all copper alloys at present covered by B.S. specifications for tubes, and also certain other copper alloys considered by the responsible committee to be in sufficient demand in industry to warrant their inclusion.

Section I includes clauses which are of general application, including the nature of tests applicable to some or all of the alloys in tube form; Section II gives the compositions, properties, quality, condition, etc., required in tubes of the individual materials, and Section III contains information on requirements taken from existing specifications for wrought products, where these differ from, or are additional to, those given in Sections I and II.

The publication opens with a tabular summary of the chemical compositions of wrought copper and copper alloys of interest in connexion with

tubing. The types for which details are given include five varieties of copper; copper-tellurium and copper-cadmium alloys; twenty-four types of brass; 95-5 and 90-10 copper-nickel alloys containing iron; 85-15, 80-20, and 70-30 copper-nickel, and iron-containing 70-30 copper-nickel; phosphor bronzes and aluminium bronzes; leaded nickel brasses; seven grades of nickel-copper-zinc (nickel silvers); copper-silicon alloy.

Appendix A gives Constants and Reciprocals of Constants for Converting Resistances at Various Temperatures to the Standard Temperature of 20°C.

Appendix B comprises photomicrographs showing Standard Grain Sizes of Brass (reproduced by courtesy of A.S.T.M.)

Chromium: A.C.S. Monograph

M. J. UDY: 'Chromium. Vol. II. Metallurgy of Chromium and its Alloys.'
Amer. Chemical Soc. Monograph Series.
Published by *Reinhold Publishing Corpn., New York*; *Chapman and Hall, London*, 1956; 402 pp. Price 88/-.

This is one of the regular series of A.C.S. Monographs which are compiled with the dual purpose of making available to chemists working in more or less unrelated fields a thorough treatment of a specific subject, and of stimulating further research. Extensive references to the literature are an essential feature of the series.

The information contained in this volume, compiled in accordance with the above purpose, is presented in three main sections, dealing, respectively, with the recovery of chromium from its ores and the deposition of chromium coatings; the physical properties of chromium and its alloys, and their metallurgical uses; and chromium in refractories. The chapters in each section have been prepared by specialists in the individual aspects of the subject. In relation to chromium as used in association with nickel, the following sections are of particular interest; chromium in austenitic steels, in cast iron, in high-temperature alloys, in nickel-base alloys, and in electrical-resistance alloys.

Cast Metals Handbook

See abstract on p. 178.

Welding of Nickel and High-Nickel Alloys

G. R. PEASE: 'The Practical Welding Metallurgy of Nickel and High-Nickel Alloys.'
Internat. Inst. Welding, Preprint, July, 1957; 7 pp.
Reprinted in *Welding Jnl.*, 1957, vol. 36, July, pp. 330S-4S.

Nickel in commercially important forms is always alloyed with some other elements; even the commercially-pure metal may contain up to $\frac{1}{2}$ per cent. of other constituents, and most of the high-nickel alloys include at least 10, and often 30-40, per cent. of other elements. This paper reviews the present state of knowledge with regard to the effect, on weldability, of twenty elements which, singly or in association with one another, may be present in nickel-base alloys.

Following brief reference to the welding characteristics of nickel in its purest, (electrodeposited), form, a review is made of the influence of the elements found in various nickel alloys and of precautions which are desirable in welding nickel-base materials in which the respective additions are present. Copper, chromium, iron and cobalt, which form binary solid solutions with nickel, have little effect on welding characteristics and this is generally true for manganese also. Sulphur, phosphorus, zirconium, boron and lead, however, are practically insoluble in nickel, and can initiate hot cracking. The effect of small amounts of aluminium, titanium, carbon, molybdenum and silicon varies, but these too may induce hot cracking if the critical tolerances of nickel for the respective elements are ignored. Gaseous elements, such as oxygen, nitrogen and hydrogen, may cause porosity if uninhibited, but cracking is usually not traceable to this source.

Self-Fluxing Brazing Alloys containing Nickel

See abstract on p. 193.

NICKEL-IRON ALLOYS

Structure of Nickel-Alloy Magnets

H. B. HAANSTRA, J. J. DE JONG and J. M. G. SMEETS: 'The Sub-Microscopic Structure of Ticonal G Magnet Steel.'* *Philips Tech. Rev.*, 1957-58, vol. 19, July 27, pp. 11-14.

The alloy discussed is of the following composition: iron 51, cobalt 24, nickel 14, aluminium 8, copper 3, per cent. When cooled at a pre-determined rate, in a magnetic field, and subsequently annealed, this material is anisotropic and has excellent permanent-magnet properties: $(BH)_{max}$ about $5{\cdot}0\times10^6$ gauss-oersted, measured in the direction of the field applied during cooling. Still better values are obtainable in single crystals of the alloy, by ensuring that during cooling the (100)-direction is parallel to the direction of the applied field: a value of $(BH)_{max}$ $8{\cdot}0\times10^6$ gauss-oersted has thus been achieved. This short note illustrates the submicroscopic structure of the alloy, using a three-dimensional impression built up from electron-microscope photographs.

Magnetism and Magnetic Materials

It should be noted that the abstracts appearing in *Nickel Bulletin*, 1957, vol. 30, No. 6, pp. 93-6 relate to papers presented at the First Conference on Magnetism and Magnetic Materials, held in 1955.

Papers from the Second Conference, held in 1956, are noted below.

'Second Conference on Magnetism and Magnetic Materials.'
Published by *Amer. Inst. Electrical Engineers, New York*, Feb., 1957; 681 pp. Price $7.50.

The papers presented covered the theoretical aspects

* Alnico V is a similar alloy.

of the subject, the composition, treatment and properties of many types of magnetic material, and methods of evaluation of their quality and characteristics. Some papers which have particular relevance to nickel-containing materials are referred to below.

R. M. BOZORTH: 'Review of Magnetic Annealing.'
Proc. 2nd Conference on Magnetism and Magnetic Materials, Boston, 1956, pp. 69–75.

The paper is a review of experimental results obtained by heat-treatment of materials in a magnetic field, and of the theories which have been advanced to explain the effects so produced. The materials considered in this connexion include (1) permanent-magnet alloys of the nickel-aluminium-cobalt-iron types, (2) magnetically soft alloys of the iron-cobalt-nickel and iron-silicon systems, (3) thin films of magnetic alloys and of unalloyed iron, cobalt and nickel, and (4) ferrites. The review is supported by a *bibliography* of 33 items.

R. W. HOFFMAN and A. M. EICH: 'Magnetization of Nickel Films at Low Temperatures.'
Proc. 2nd Conference on Magnetism and Magnetic Materials, Boston, 1956, pp. 78–84.

The relative magnetization of evaporated nickel films was measured as a function of thickness, over the temperature range from 10° to 300°K. (−263° to +27°C.). Full details are given of method of preparing the films and of technique used in evaluation of properties.

A. J. J. KOCH, M. G. V.D. STEEG and K. J. DE VOS: 'A Contribution to the Study of Permanent-Magnet Alloys of the Fe-Co-Ni-Al Type.'
Proc. 2nd Conference on Magnetism and Magnetic Materials, Boston, 1956, pp. 173–83.

The paper reports a study of the mechanism responsible for the high coercive force obtainable in alloys of the Ticonal type. A representative alloy of this group is Ticonal G (known in U.S.A. as Alnico V), which has the nominal composition cobalt 24, nickel 14, aluminium 8, copper 3, per cent., balance iron. Phase relationships were examined in this alloy and in two modified Ticonal alloys containing, respectively, additions of 5 per cent. of titanium and 2 per cent. of niobium. Both these elements are known to increase coercive force. Structure and magnetic properties are correlated, and the effect of modified heat-treatments was investigated.

E. A. NESBITT and A. J. WILLIAMS: 'Nucleation Experiments on Alnico V.'
Proc. 2nd Conference on Magnetism and Magnetic Materials, Boston, 1956, pp. 184–7.

The experiments described were also designed to elucidate the mechanism responsible for the high coercive force producible in Alnico V-type alloys by heat-treatment in a magnetic field. In considering this effect, two ranges of temperature are visualized; first the range 890°–790°C., in which thermal nucleation of the precipitate occurs, and second, the 790°–550°C. region, in which the particles of precipitate grow. In specimens for which the magnetic field was applied only during the thermal-nucleation stage, followed by rapid cooling to room temperature and subsequent ageing at 600°C., properties characteristic of Alnico V were obtained. When the field was applied only during the precipitate-growth stage and the alloy was then aged at 600°C., low energy products were obtained. The results thus indicate that the magnetic treatment is effective mainly during the range of thermal nucleation of the precipitate.

R. K. TENZER: 'Effects of Temperature Variations on the Remanence of Permanent Magnets.'
Proc. 2nd Conference on Magnetism and Magnetic Materials, Boston, 1956, pp. 203–11.

It is common experience that the remanence of permanent magnets varies with change in temperature. This paper reports evaluation of six materials, on the basis of their susceptibility to irreversible and reversible change of remanence with temperature over the range −60° to + 350°C. The materials examined were a barium ferrite, a nickel-copper-iron alloy (Cunife) and three of the nickel-aluminium-cobalt-iron alloys (Alnicos 3, 5 and 6).

R. E. S. WALTERS: 'Heat-Treatment for High Initial Permeability in Binary and Complex Nickel-Iron Alloys containing about 75% Ni.'
Proc. 2nd Conference on Magnetism and Magnetic Materials, Boston, 1956, pp. 258–67.

The paper deals mainly with the effects, on the magnetic and electrical properties of nickel-iron and nickel-iron-molybdenum alloys, of quenching from temperatures in the range 500°–1050°C., i.e., a range well above the critical point for long-range order. All the specimens used were prepared by powder-metallurgical techniques. The annealing treatments were carried out in an atmosphere of pure hydrogen, in recrystallized-alumina tubes. The paper deals with the effects of adding molybdenum to nickel-iron alloys of various nickel contents, and with the Mumetal type of alloy (nickel 77, iron 14, copper 5, molybdenum 4, per cent.).

Measurements of resistance at elevated temperatures showed that the addition of molybdenum to nickel-rich nickel-iron alloys encourages superlattice formation. The response of an alloy of the Mumetal type to cooling at various rates is found to be consistent with the theory that development of maximum initial permeability depends on the production of a critical degree of long-range order.

Initial permeability of Ni_3Fe and many other nickel-rich alloys is at a maximum after quenching from 600°C. It is suggested that alloys of which the compositions lie close to the line $4Fe+13Mo=100$ in the nickel-iron-molybdenum diagram may be regarded as consisting of a Ni_3Fe matrix in which clusters of $MoNi_{12}$ are dispersed.

A. E. BERKOWITZ and P. J. FLANDERS: 'Magnetic Measurements of a Ni-Au Alloy.'
Proc. 2nd Conference on Magnetism and Magnetic Materials, Boston, 1956, pp. 275–84.

A considerable amount of evidence (to which the authors direct reference) indicates that many of the permanent-magnet alloys derive their 'hard' magnetic properties from ferromagnetic precipitate particles in the single-domain size-range. The particles are generally assumed to be embedded in a non-magnetic or weakly magnetic matrix. The magnetic properties of the alloy can then be described by treating the system as an assembly of single-domain particles, using the current theories of fine-particle ferromagnetism. This paper reports a study of the nickel-gold system, examined as a prototype of the more complex permanent-magnet alloy systems. The examination was confined to the very earliest stages of precipitation, with the fraction of precipitate less than one per cent. of the available nickel. Measurements of torque and saturation moment were found to give useful information in that region of composition.

R. S. SERY, R. E. FISCHELL and D. I. GORDON: 'Effects of Nuclear Irradiation on Magnetic Materials.'
Proc. 2nd Conference on Magnetism and Magnetic Materials, Boston, 1956, pp. 453–71.

Study of the influence of irradiation on the magnetic characteristics of seven typical magnetic materials, representative of those used in cores employed in various forms of apparatus: 50–50 ferrite, 2–81 Molybdenum-Permalloy (powder core), 5–79 Molybdenum-Permalloy, 3·5 per cent. silicon-iron, Orthonol (50–50 nickel-iron alloy), 16 Alfenol (aluminium-iron-alloy) and 2 per cent. Vanadium-Permendur (cobalt-iron-base alloy). Most of the materials were in the form of laminated toroids, and the Orthonol was tested as a toroidal tape-wound core. The materials were irradiated in a nuclear reactor for about 17 days, at a neutron flux of $1 \cdot 8 \times 10^{12}$ neutrons per square centimetre per second. Before and after irradiation, measurements were made of all major magnetic properties. Much detailed information is given with regard to preparation of the cores, experimental conditions, and the results obtained on each of the materials.

The reaction of the respective materials to irradiation placed them in two groups, those showing little change in magnetic properties and those affected to a major degree. Certain similarities of behaviour were, however, noted throughout the seven materials

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R. L. CONGER: 'High-Frequency Effects in Magnetic Films.'
Proc. 2nd Conference on Magnetism and Magnetic Materials, Boston, 1956, pp. 610–19.

The paper is based on work which has been directed primarily to provision of faster and less expensive coincident-current memories for high-speed digital computers. The experiments have demonstrated that very thin evaporated magnetic-alloy films are suitable for such memories and that the use of evaporation techniques, in conjunction with printed-circuit methods, can much reduce the cost of the present type of coincident-current memory, which is made from separate ferrite cores. In addition to that application, the investigation of magnetic films has shown that they are useful in the study of the dynamics of magnetization reversal.

This paper describes methods which are used for preparation of the evaporated films and the techniques employed for investigation of their magnetic properties. Reference is made to work on 80–20 nickel-iron, 85–15 cobalt-iron and 48–27–25 nickel-cobalt-iron alloys.

D. O. SMITH: 'Magnetic Relaxation in Thin Films.'
Proc. 2nd Conference on Magnetism and Magnetic Materials, Boston, 1956, pp. 625–40.

Static and dynamic theories are proposed to describe the behaviour of thin magnetic films having a uniaxial anisotropic energy, and the theory is extended to treatment of the problem of domain-wall motion. The supporting data presented include consideration of vacuum-evaporated films of 80–20 nickel-iron alloy (Permalloy).

O. J. VAN SANT: 'Magnetic Viscosity in 4–79 Moly Permalloy.'
Proc. 2nd Conference on Magnetism and Magnetic Materials, Boston, 1956, pp. 641–53.

In analysing the behaviour of the magnetic shift register, it was observed that an important relation exists between B, H and time. This relation is considered as demonstrated in 4–79 Molybdenum-Permalloy.

Magnetic and Magnetostrictive Properties of Magnesium-Nickel Ferrites

P. O. HOFFMANN: 'Magnetic and Magnetostrictive Properties of Magnesium-Nickel Ferrites.'
Jnl. Amer. Ceramic Soc., 1957, vol. 40, July 1, pp. 250–2.

The paper reports comparison of the properties of nickel-magnesium ferrites of various compositions and those of a simple nickel ferrite.

The investigation was carried out on ferrite specimens of eight different compositions. The ferric-oxide content was maintained at 50 molecular per cent. in each case, while the nickel oxide was increased gradually from zero to 50 per cent. and the magnesium oxide was simultaneously decreased from 50 to zero per cent. Details are given of the fabrication of the ferrites and of the methods used to determine their magnetic and magnetostrictive properties.

A summary of the results, shown in graphs as a function of composition, is given below:

Density increased with rising nickel-oxide content, from 4·45 g./cm.^{3} for the magnesium ferrite to 5·00 g./cm.^{3} for the nickel ferrite. Shrinkage (about 17 per cent.) was substantially identical for

all the ferrites used. Modulus of elasticity fell from $1{\cdot}92\times10^{12}$ dyne per cm.^{2} for the magnesium ferrite to $1{\cdot}68\times10^{12}$ dyne per cm.^{2} for the nickel ferrite. This change was reflected in the resonance frequencies, which changed from 39·2 to 34·7 kc. Reversible permeability gradually increased with rising nickel-oxide content, reaching a maximum value of about 10 for the 50 per cent. nickel ferrite. Coercivity decreased with increase in nickel oxide, until a minimum value of 8·4 oersteds was reached for a pure nickel ferrite. Remanence rose uniformly from 770 gauss for the magnesium ferrite to the high value of 1770 for the nickel ferrite.

The static magnetostrictive strain at saturation increased uniformly from -7×10^{-6} for the 40% MgO, 10% NiO ferrite to -21×10^{-6} for the nickel ferrite. Dynamic measurements showed that the electrochemical coupling coefficient also increased three-fold with increase in nickel-oxide content.

The results clearly indicate that, so far as magnetic and magnetostrictive properties are concerned, the simple nickel ferrite is superior to a mixed nickel-magnesium type.

Sulphide Corrosion Cracking of Nickel-Iron Alloys

See abstract on p. 192.

CAST IRON

Cast Metals Handbook

See abstract on p. 178.

Chromium in Cast Iron: A.C.S. Monograph

See abstract on p. 180.

CONSTRUCTIONAL STEELS

Cast Metals Handbook

See abstract on p. 178.

Chromium in Steel: A.C.S. Monograph

See abstract on p. 180.

HEAT- AND CORROSION-RESISTING MATERIALS

Influence of Crucible Materials in Vacuum Melting

R. F. DECKER, J. P. ROWE and J. W. FREEMAN: 'Influence of Crucible Materials on High-Temperature Properties of Vacuum-Melted Nickel-Chromium-Cobalt Alloy.'

Nat. Advisory Committee for Aeronautics, Tech. Note 4049, June 1957; 34 pp.

During experiments made to study the effect of melting-practice variables on high-temperature properties of a nickel-chromium-cobalt-base alloy, a relationship was established between the type of refractory used in induction melting, and the high-temperature properties of the material. The alloy under consideration had the following composition: nickel 55, chromium 20, cobalt 15, molybdenum 4, titanium 3, aluminium 3, per cent. The high-temperature properties were evaluated by stress-rupture testing at 1600°F. (870°C.), with 25,000 p.s.i. (11 tons per sq. in.) load. The main conclusions drawn from the tests are summarized below.

Heats made in alumina crucibles showed comparatively short rupture life, and low ductility, with high susceptibility to cracking.

Melting in zirconia crucibles had a beneficial effect, resulting from reactions with the refractory, which introduced zirconium into the alloy. Pronounced benefits to rupture life, ductility and resistance to cracking resulted also from the use of magnesia crucibles: in this case the improvement appeared to be due to the presence of boron, derived from the crucible material. Addition of zirconium or boron, to heats melted in alumina crucibles, produced material having properties similar to those obtained from heats which derived the two elements by melting, respectively, in zirconia or magnesia crucibles.

The addition of boron+zirconium, in optimum amounts, gave stress-rupture properties superior to those obtained by the use of either of these additions singly. The data reported indicate that amounts in excess of the optimum zirconium+boron addition have a deleterious influence on rupture properties and lead to susceptibility to cracking during hot working.

The authors make the following comment with regard to the wider interest of the observations made:

'The results serve to clarify many puzzling and seemingly contradictory variations in properties in both experimental and commercial heats. In particular, variable boron pick-up from the magnesia refractories generally used in commercial vacuum melting could explain many of the variations. Unrecognized introduction of boron or zirconium with melting stock could be another source of variability. Inter-relationships between boron and zirconium content, leading to low strength beyond certain amounts, are probably a source of misunderstood low strengths when such elements have been purposely added.'

Phase Relations in Precipitation-Hardened Austenitic Steels

H. J. BEATTIE and W. C. HAGEL: 'Intermetallic Compounds in Titanium-Hardened Alloys.'

Trans. Amer. Inst. Mining and Metallurgical Engineers, 1957, vol. 209, pp. 911–17;
Jnl. of Metals, July 1957, Sect. II.

During earlier examination of a high-temperature steel, A-286, the presence of an unknown intermetallic compound was verified by X-ray diffraction (*Nature*, 1956, vol. 178, p. 208; *Nickel Bulletin*, 1957, vol. 30, No. 1, p. 12). Due to the prominent

appearance of the phase at the grain boundaries, the designation *G*-phase was arbitrarily assigned. Since it was observed that in low-silicon vacuum-melted heats of the alloy no *G*-phase was present, further work was initiated to determine the influence of silicon on formation of the phase, and the research was extended to examination of other intermetallic compounds present in the A-286 type of alloy, and the ageing reactions occurring in this group.

The compositions studied covered the following variables: typical A-286 low-carbon 25-15 nickel-chromium steels containing small amounts of molybdenum, titanium, aluminium and vanadium, with silicon 0·67-0·92 per cent.; varying silicon, up to 1·75 per cent.; titanium over the range 0·39 to 2·24 per cent.; and aluminium varying from 0·16 to 2·40 per cent.

A range of thermal solution and ageing treatments provided for study of the influence of the temperatures of the two stages.

The ageing reactions were studied by means of light and electron microscopy, X-ray examination and electron diffraction. It is concluded that maximum dispersion hardening is provided by low-aluminium γ'. At temperatures above 1400°F. (760°C.) η platelets are observed. *G* phase is identified as a globular nickel-titanium silicide resulting from grain-boundary segregation. Bulky Laves phase appears only after most of the excess nickel in high-titanium alloys has combined with γ', η and *G* phases. Similarly, σ-phase forms in high-aluminium alloys of this type when excess nickel combines with γ'. The ageing characteristics of vacuum-melted A-286 of negligible silicon content are based on γ' and η phases, but instead of *G* or Laves phases there is a cellular precipitation, involving a new phase.

Temperature Dependence of Secondary Phases in High-Temperature Alloys

J. H. WESTBROOK: 'Temperature-Dependence of the Hardness of Secondary Phases Common in Turbine-Bucket Alloys.'
Trans. Amer. Inst. Mining and Metallurgical Engineers, 1957, vol. 209, pp. 898-90.
Jnl. of Metals, July 1957, Sect. II.

Within the past few years much research has been devoted to identification of the secondary phases present in the more or less empirically developed alloys which have proved suitable for gas-turbine blading and other high-temperature-engineering applications: see, for example the series of papers which have reported studies on the γ' phase in nickel-chromium-base alloys hardened by titanium and aluminium. Comparatively little attention has, however, yet been given to the mechanisms by which such phases enhance the properties of the alloys, and to the properties of the secondary phases themselves, either intrinsically or in relation to the matrix of the alloys in which they are present.

The present paper makes a contribution to the subject by an account of the temperature-dependence of the hardness of representative secondary phases which have been found in various high-temperature alloys. The aim has been to cover the range room temperature to the present service temperatures of the alloys in which the respective phases occur. The paper opens with a useful table of common microconstituents which have been identified in (1) chromium-nickel steels, (2) cobalt-base alloys, (3) nickel-base alloys, (4) alloys of complex composition, and (5) chromium-base alloys. Reference to information on the respective phases is given in an extensive *bibliography* which is correlated with the tabular matter.

Representative examples of the various types (with the exception of the monocarbides and carbonitrides, which are to be the subject of a separate report) were synthesized in bulk, and their hardness was measured from room temperature to 800°C. The values for the secondary phases are compared, at given temperatures, with those of the alloys in which they are present, in order to establish the significance of the constituents *per se*. Among the conclusions drawn from the considerable amount of data presented are the following:

At room temperature there is a wide variation in hardness among the secondary constituents, but except for Ni_3Al all the compounds studied are significantly harder than the corresponding high-temperature alloy. At 800°C. the spread of hardness among the phases is considerably lessened, but distinct differences still exist. At that temperature all the secondary phases are notably harder than their respective typical high-temperature alloys. The hardnesses at 800°C. of some of the secondary phases are among the highest values ever reported for any material. The spread in hardness which still exists among the secondary phases at 800°C. may indicate that other properties also play a determining part with respect to the high-temperature strength of the alloys.

It is suggested that useful information might be obtained by measurements on a series of synthetic alloys in which the various secondary phases were added to a common solid-solution matrix.

Phase Relationships in High-Manganese Austenitic Steels

E. J. WHITTENBERGER, E. R. ROSENOW and D. J. CARNEY: 'Elevated-Temperature Phase Relationships in the Cr-Ni-Mn-N System.'
Trans. Amer. Inst. Mining and Metallurgical Engineers, 1957, vol. 209, pp. 889-95; *T.P.* 4463*E*.
Jnl. of Metals, July, 1957, Sect. II.

In the high-manganese, high-nitrogen, low-nickel stainless steels precipitation of δ ferrite causes poor workability when large ingots are heated to temperatures sufficiently high for conversion to slabs. The establishment of the austenite/austenite+ferrite phase boundaries is therefore of obvious importance in the development of such steels. To that end, this paper presents data assembled in a high-temperature constitutional study of the chromium-nickel-manganese-nitrogen system. The composition ranges covered were chromium 15-21, nickel 0-3, manganese 12-18, nitrogen 0·25-0·45, per cent.

The results confirm that nickel and nitrogen contribute strongly to formation of austenite, that chromium strongly favours production of δ ferrite, and that manganese has a similar, but less potent, influence. Some 3 per cent. of δ ferrite is formed as the result of the presence of ½ per cent. of chromium in excess of the limit of austenite stability at 2300°F. (1260°C.). At that temperature an increase of 1 per cent. of nickel or 0·05 per cent. of nitrogen permits an increase in chromium content of about 0·60 per cent. without decrease in stability of austenite. Increasing chromium and manganese enhances the solid solubility of these steels for nitrogen. A steel containing carbon 0·10, chromium 17·50, manganese 14·50, nitrogen 0·40, per cent. was found to be completely austenitic at hot-working temperatures as high as 2300°F. (1260°C.).

Order-Disorder Transitions in Nickel-Chromium Alloys

See abstract on p. 178.

Ageing in Complex Nickel-Chromium Alloys

R. F. WILDE and N. J. GRANT: 'Ageing in Complex Commercial Ni-Cr Alloys Hardened with Titanium and Aluminium.'
Trans. Amer. Inst. Mining and Metallurgical Engineers, 1957, vol. 209, pp. 865–72; *T.P.* 4430*E*.
Jnl. of Metals, July 1957, Sect. II.

The authors refer to earlier investigations by Taylor and Floyd and by Nordheim and Grant, which have elucidated the mechanism of precipitation hardening in nickel-chromium-base alloys hardened with titanium and aluminium within specified limits. The work reported in the present paper was concerned with the more complex commercial alloys containing higher amounts of titanium and aluminium, and also significant quantities of cobalt, molybdenum and carbon. The alloys examined as typical are shown in the table below, with details of grain-size of the bar stock in various conditions.

All the material was received as forged bar stock: the Waspaloy was ⅜-in. diameter, the other materials were re-forged to that diameter. Forging was carried

Element wt.%	Inconel X 550 (Air-melted)	Inco 700 (Air-melted)	Waspaloy (Induction vacuum-melted)	M–252 (Induction vacuum-melted)
Nickel	72·39	44·99	55·5	54·8
Chromium	15·15	15·05	19·7	19·7
Cobalt	—	30·73	14·1	9·6
Molybdenum	—	3·22	4·2	9·9
Titanium	2·50	2·19	3·25	2·52
Aluminium	1·17	3·02	1·39	1·04
Iron	0·68	0·38	0·75	0·84
Manganese	0·70	0·05	0·30	1·0
Sulphur	0·007	0·007	0·006	0·004
Silicon	0·33	0·19	0·49	0·53
Carbon	0·04	0·13	0·09	0·12
Nitrogen	n.d.	0·015	n.d.	n.d.
Copper	0·04	0·02	0·1	n.d.
Niobium + Tantalum ..	0·97	—	—	—
Magnesium	n.d.	n.d.	0·01	n.d.

Grain-Size, A.S.T.M., As received	7-8	6-7	6-7	6-7 some 4-5
Re-forged + solution treatment at 1900°F. (1038°C.)	5-6 some 2	5-6	5-6	5-6
Re-forged + solution treatment at 2200°F. (1205°C.)	1	1-3	2-5	2-6 some 1

out at 2100°F. (1150°C.) and discontinued when the temperature fell to 1800°F. (980°C.). The following heat-treatments were applied:

A. Solution-treated at 2200°F. (1205°C.) for 2 hours; air-cooled; aged at 1600°F. (870°C.) for 24 hours.

B. Solution-treated at 2200°F. (1205°C.) for 2 hours; air-cooled; aged at 1200°F. (650°C.) for 24 hours.

C. Solution-treated at 1900°F. (1040°C.) for 6 hours; air-cooled; aged at 1600°F. (870°C.) for 24 hours.

D. Solution-treated at 1900°F. (1040°C.) for 6 hours; air-cooled; aged at 1200°F. (650°C.) for 24 hours.

Electrolytically extracted residues were obtained from bars solution-treated at 2000°F. (1095°C.), air-cooled, and aged for 50 or 250 hours at 1500°F. (815°C.) and from bars solution-treated at 2200°F. (1205°C.), air-cooled and aged for 24 hours at 1600°F. (870°C.).

Alloys in the aged condition were electrolytically etched in a solution containing 2 per cent. each of HCl and Cr_2O_3; voltage 2·5, treatment for 30 seconds.

Solution-treated specimens were immersion-etched in a solution containing 97 per cent. HCl, 2 per cent. H_2SO_4 and 1 per cent. HNO_3. Time 30 seconds to 2 minutes.

The paper includes photomicrographs indicating the structure of the alloys in the respective conditions.

Stress-rupture tests were made at 1500° and 1600°F. (815° and 870°C.), on specimens of all the alloys in the various conditions of thermal treatment. The results are shown in terms of stress for rupture in 1, 10, 100 and 1000 hours, and details are given of 100-hour rupture-life ductility.

The main conclusions drawn from the large amount of experimental data reported are summarized below:

As in the simpler alloys examined in earlier investigations, there is ample evidence that $Ni_3(Al,Ti)$, or γ' is the ageing precipitate in Inconel X550, Inco 700 and Waspaloy. That phase was not identified in M-252, which differs from the other alloys in that it has a matrix parameter larger than that of γ,' a difference which is associated with its high molybdenum content.

It appears that air-cooling of sections less than about $\frac{1}{2}$-in. in diameter fails to maintain all the aluminium and titanium in solution in these alloys, except possibly in Inconel X550 cooled from 1900°F. (1040°C.). It is also likely that in Waspaloy and Inco 700 more severe quenches also fail to keep these elements in solution. The hardening and embrittlement observed in Inconel X550 after the 1900° + 1200°F. (1040° + 650°C.) treatment, and the relatively slight response to ageing found in Waspaloy support these observations. It is considered that the more highly alloyed Inco 700 and Waspaloy, in which some precipitation of γ' occurs on cooling from the solution temperature, escape embrittlement because they are somewhat overaged prior to the actual ageing treatment. Similar over-ageing of Inconel X 550, either by 2200°F. (1205°C.) treatment (as compared with treatment at 1900°F. (1040°C.)), or by deliberate overaging at 1600°F. (870°C.), also prevents such embrittlement, without loss of strength at 1500°F. (815°C.) and with significant increase in ductility.

In spite of the absence of the γ' precipitate, the M-252 alloy showed better creep-rupture properties than Inconel X550 at 1500°F. (815°C.). It is probable that the carbide precipitation noted in the M-252 alloy is responsible for these properties in a material which otherwise relies on solid-solution strengthening. It is suggested that Waspaloy and Inco 700 may also profit to some extent from carbide precipitation, and that further study should be made of the rôle of carbon in those alloys. The results of the tests reported, while not minimizing the significance of the γ' precipitate, point to the fact that carbide strengthening may have a greater importance than has hitherto been realized.

Properties of Vacuum-Melted High-Temperature Alloys

F. M. RICHMOND: 'High-Temperature Properties of Vacuum-Melted Super Alloys.'
Soc. Automotive Engineers, Preprint 90, Apr. 1957; 14 pp. + tables and figures.

It is pointed out that the road of high-temperature-alloy development has several outstanding milestones marking progress in processing techniques, e.g., the use of hot-cold working, the evolution of precision-casting methods, controlled forging procedures, and, still more recently, the introduction of vacuum melting.

This paper draws attention to some of the improvements which have been effected in the high-temperature properties of typical nickel-chromium-(cobalt)-base alloys by vacuum-melting technique and by the recognition of the significance of minor amounts of addition elements, in particular zirconium and boron. (Cf. paper referred to in abstract on p. 183). The materials for which data are recorded are J-1570, G.M.R.-235, Udimet 500, M-252, and Waspaloy.

Nickel-base Alloys for Cooled Turbine Blades

J. H. DANCE and F. J. CLAUSS: 'Rupture Strength of Several Nickel-base Alloys in Sheet Form.'
Nat. Advisory Committee for Aeronautics, Tech. Note 3976, Apr. 1957; 24 pp.

Current trends in jet design are towards increasing air flow and raising gas temperatures. Air cooling is one of the methods used to make it possible for the blading to operate effectively in spite of the higher stresses and temperatures which these improvements entail. Some of the most promising designs of cooled turbine blades have shells of sheet metal, and air is blown through the blades to lower the temperature of the metal to a point at which its strength is sufficient for efficient operation. In

some cases the temperature may be thus lowered to 1200°F. (650°C.).

Whilst cobalt- and nickel-base alloys are widely used for conventionally cast and forged blades operating at 1500°F. (815°C.), there are few published data on the properties of such materials at lower temperatures, in the sheet form in which they are being considered for cooled turbine blades. Data on bar-stock and sheet for the higher temperatures suggest that some of the established nickel-base alloys may be stronger at 1200°F. (650°C.) than other materials in sheet form, but predictions based on such data are liable to be misleading. The work reported in this Note was therefore carried out to determine the 100-hour rupture strength for several nickel-base sheet alloys (see table below), at temperatures which might be reached in air-cooled blades, *viz.*, 1200° and 1350°F. (650° and 730°C.). The properties found were compared with those of other oxidation-resisting materials available in sheet form.

The sheet varied in thickness from 0·038 to 0·050 in. and each alloy was tested in both the annealed and the solution-treated-and-aged conditions. In heat-treatment, an argon atmosphere was used to minimize surface corrosion.

The rupture data are correlated with the structure of the alloys in the various conditions.

From the results the authors conclude that:

'(1) At 1200° and 1350°F. (650° and 730°C.) the best nickel-base sheet alloys have 100-hour rupture strengths higher than those of other oxidation-resistant sheet alloys for which data are available.

'(2) Of the nickel-base alloys studied, Inconel 700 and Incoloy 901 were strongest at 1200°F. (650°C.). The strongest alloys at 1350°F. (730°C.) were Inconel 700 and R-235.

'(3) The precipitation-hardening treatments used in this investigation strengthened all five alloys when tested at 1200°F. (650°C.), whereas at 1350°F. (730°C.) only Inconel X, Inconel 700, and R-235 were so strengthened.

'(4) Nickel-base sheet alloys generally lack the ductility of cobalt- and iron-base alloys in sheet form. Incoloy 901, which in the annealed condition gave elongations up to 20 per cent. in stress-rupture tests, was the most ductile; for the remaining nickel-base alloys elongation was only about 1-5 per cent.

'(5) Stress-rupture fractures generally occurred in the grain boundaries.

'(6) Heat-treatment raises the strength of sheet in most cases, although not to the level of heat-treated bar stock. The recommended heat-treatments for bar stock and sheet of the same alloy are, however, often not the same.'

Cast Nickel-base Alloy for Turbine Blading

R. A. SIGNORELLI, J. R. JOHNSTON and J. W. WEETON: 'Preliminary Investigation of Guy Alloy as a Turbojet-Engine Bucket Material for Use at 1650°F.' *Nat. Advisory Committee for Aeronautics, Research Memorandum E*56119, Nov. 29, 1956; 22 pp.

The development of Guy alloy, a nickel-base cast material, was announced in 1948; see *Trans. Amer. Soc. Metals*, 1949, vol. 41, pp. 125-40; *Nickel Bulletin*, 1948, vol. 21, No. 11, p. 168. The stress-rupture properties reported for the alloy indicated its potential usefulness as a turbine-blading material, and this memorandum gives results of an evaluation of the alloy for such purpose. The tests, which were carried out at the Lewis Flight Propulsion Laboratory, Cleveland, Ohio, were made on precision-cast blades of the following composition: carbon 0·1 max., nickel 64-70, chromium 12-15, molybdenum 5-6, aluminium 5·5-7, niobium 2, iron 4·5, boron 0·5, manganese 0·5, silicon 0·5, per cent. The as-cast blades were run in a turbojet engine for cycles of

Table I

Nominal Chemical Compositions of Alloys Tested in Sheet Form

Alloy	C %	Fe %	Cr %	Ni %	Co %	Mo %	Ti %	Al %	Mn %	Si %	Cu %	S %	Nb+Ta %
Inconel X	0·04	7·0	14·5	73·0	—	—	2·5	0·70	0·50	—	—	—	1·00
Inconel 700	0·16[a]	4·0[a]	13·0–17·0	Bal.	24·0–34·0	1·0–4·5	1·75–2·75	2·5–3·5	2·0[a]	1·0[a]	0·5[a]	0·015[a]	—
Incoloy 901	—	Bal.	11·0–14·0	40·0–45·0	—	5·0–7·0	2·0–3·0	—	—	—	—	—	—
Refractaloy 26	0·05	17·5	18·0	37·0	20·0	3·0	2·8	0·20	0·70	0·80	—	—	—
R-235 ..	0·16[a]	9·0–11·0	14·0–17·0	66·0	2·5[a]	4·5–6·5	2·25–2·75	1·75	1·0[a]	1·0[a]	—	—	—

[a] maximum

15 minutes at rated speed and 5 minutes at idle speed. Stress-rupture, impact and engine-performance data recorded indicate that the material may be considered for use in blading at a temperature of 1650°F. (900°C.). The ductility and impact strength of the alloy are limited, but appear to be adequate for this application.

Precipitation-Hardening Nickel-Chromium Sheet Material

'Alloy Sheet, Corrosion- and Heat-Resistant.'
Soc. Automotive Engineers.
A.M.S. Specification 5541, Jan. 7, 1957.

Covers material, of the percentage composition shown below, to be used for parts requiring high strength up to 1500°F. (815°C.) and oxidation-resistance up to 1800°F. (980°C.).

Carbon 0·08 max., manganese 1·0 max., silicon 0·7 max., sulphur 0·01 max., chromium 14·0–17·0, nickel+cobalt 70·0 min., cobalt (if determined) 1·0 max., titanium 2·0–2·75, aluminium 0·40–1·0, iron 5·0–9·0, copper 0·50 max.

Tensile and bend properties are specified for sheet in the annealed condition; precipitation heat-treatment is detailed and requirements are laid down for tensile properties, hardness and grain-size in the hardened condition.

Nickel-containing Materials in the Gyron Turbojet

'Gyron: De Havilland's Supersonic Turbojet with 25,000-lb. Re-Heat Rating.'
Flight, 1957, vol. 72, Aug. 2, pp. 163–8.

Although the De Havilland Gyron DGy. 1, the first truly supersonic turbojet, ran in January 1953, information on design, construction and performance has only recently been released. This article reviews the four-year history of the rig and flight development of the engine (which, with re-heat, now develops a thrust of 25,000 lb.). Full details are given (with cut-away drawing showing design) and the main engine components are described. As in other British aircraft gas turbines in current production, many of the major components are in high-nickel alloys, e.g., turbine rotor blades in the first and second stages are, respectively, of Nimonic 100 and Nimonic 90; first and second-stage nozzle blades are of Nimonic 80A, and for the flame tubes and a large part of the exhaust cone assembly Nimonic 75 is used.

Residual Stress Produced in High-Temperature Alloys by Grinding

R. D. HALVERSTADT: 'Analysis of Residual Stress in Ground Surfaces of High-Temperature Alloys.'
Amer. Soc. Mechanical Engineers, Paper 57-*SA*-62, June 1957; 12 pp.

The need for more extensive research on the nature, magnitude and effects of residual stress has recently been emphasized by three considerations:

(1) The apparent vulnerability of high-temperature alloys to residual stresses introduced during processing.

(2) The need for high design stresses in producing lighter airframes and engines.

(3) The lighter cross sections of most jet-engine parts, and, hence, the higher distortions introduced by stresses.

The work described in this paper was a quantitative analysis of the residual-stress levels resulting from grinding three typical high-temperature alloys: a martensitic stainless steel (Lapelloy), and two precipitation-hardening alloys, A-286* and M-252†. The three materials were chosen for examination as representing alloys used for service in three different temperature ranges. Grinding conditions, which are fully detailed in the paper, provided for variation in wheel speed, table speed, depth of cut, wheel hardness, and grinding fluid. The influence of each of these variables is reported for the individual materials.

The general conclusions drawn are as follows:

(1) The depth and level of residual stresses resulting from surface grinding the high-temperature alloys appear to be greater than for alloy steels ground under equivalent conditions.

(2) Tensile residual stresses can be lowered and depth of penetration can be reduced by:

(*a*) Reducing wheel speed.
(*b*) Reducing down feed.
(*c*) Use of sulphurized grinding oil, in optimum conditions.
(*d*) Use of 'soft' grinding wheels.

(3) Increasing work speed reduced depth of penetration in this study.

(4) It is possible to grind alloys of this type with compressive stresses only.

(5) Short-time heat-treatment for stress-relief does not relieve all of the residual stress.

(6) Additional work should be performed on a representative alloy, to determine more closely the optimum combination of variables and to explore the effects of other types of grinding.

Evaluation of Nickel-containing Heating Alloys

C. D. STARR: 'Criteria for Evaluating Electrical-Resistance Units.'
Metal Progress, 1957, vol. 72, July, pp. 88–94.

The development of new and improved alloys for use at increasingly high temperatures has entailed parallel efforts to develop electrical-resistance units capable of operating at the high furnace temperatures needed to anneal and heat-treat such alloys. The article reviews the criteria which may be used for developing improved elements.

The author discusses the types of established electrical-resistance materials used in various temperature ranges and critically considers the suitability of some test methods used in evaluating the serviceability of alloys for heating units. It is concluded

* Precipitation-hardening 25-15 nickel-chromium steel.
† Precipitation-hardening nickel-chromium-cobalt-molybdenum alloy.

that there is urgent need for development of efficient heating elements to operate in the range 2150°–2600°F. (1175°–1425°C.). The pre-requisites for development of new wrought elements to work in that range are an efficient method of measuring the life of the alloys, and an evaluation of the significance of the respective variables which influence their high-temperature properties.

The standard test for nickel-chromium and nickel-chromium-iron alloys of the types so widely used as resistance materials is of the type laid down in the A.S.T.M. schedule B.76-39, the conditions of which have been adjusted, since its introduction, to provide for adequate testing of the improved alloys which have been developed during the past twenty years. The validity of that form of test for iron-chromium-aluminium resistance alloys and for silicon-carbide materials is to be doubted, for reasons which are discussed.

In considering the second pre-requisite essential in developing new alloys, viz., knowledge of the factors, beneficial and deleterious, which affect high-temperature behaviour and serviceability, the author reviews the mechanical properties needed, the deleterious effects which may arise due to lowering of the melting point by contamination of the alloy, the importance of good resistance to thermal shock, and the troubles which may arise from volatilization and oxidation. Brief mention is made of some test methods which may be used to assess the characteristics of alloys in these respects. In closing, attention is drawn to some improved alloys which have recently been introduced, e.g., nickel-chromium alloys containing aluminium, and to development work which is in hand on molybdenum alloys.

Liquid Inhibitors for Prevention of Corrosion by Vanadium and Sodium Compounds

R. S. NORRIS: 'A Liquid Additive to Limit Oil-Ash Corrosion.'
Corrosion, 1957, vol. 13, July, pp. 123–4 and 126.

The author briefly reviews the corrosion problems involved in the increasing use, in Diesel engines, gas turbines and boilers, of residual fuel oils containing considerable quantities of sulphur, vanadium and sodium. Vanadium and sodium contents of some typical blended residual-type fuels are tabulated.

Some examples are given of severe corrosion caused by contamination from fuels used in central-station boilers, and in the piston heads and valves of Diesel engines. The seriousness of the problem in the U.S.A. at the present time is demonstrated by the fact that demand for these fuels has outstripped supply.

One effective method of treatment is to remove as much of the sodium as is economically feasible by water-washing, and to inhibit the remainder by adding compounds which raise the melting point of the ash, e.g., salts or oxides of magnesium, calcium, barium or aluminium. The effectiveness of such treatment, and its economic feasibility, have, however, not yet been fully established. Some typical treatments which would be necessary to effect appreciable reduction in corrosion attack are discussed.

If the inhibitors (in slurry or powder form) are to be effective, they must be brought into intimate contact with a sufficiently high proportion of the vanadium and sodium present in the fuel oil, and such intimate admixture is favoured more by the small particle-size involved in a liquid additive than by the particles of larger size of which a powder or slurry is composed.

For example, it has been shown that magnesium oxide introduced as a slurry into the fuel at a Mg/Na ratio of 6 : 1 is less effective in raising the ash-fusion temperature than an oil-soluble aluminium-salt inhibitor in a molecular ratio of Al : Na 0·75 : 1. The relatively small capital outlay involved in introduction of a liquid additive into the fuel is urged as a further advantage of that method of treatment: a drawing illustrates typical equipment suitable for pumping-in the additives. A further argument advanced is that a liquid oil-soluble additive does not increase the ash burden of a boiler to the same extent as it is increased by introduction of a salt or oxide in slurry form.

Stress-Corrosion of Austenitic Stainless Steels in Steam and High-Temperature Water

C. EDELEANU and P. P. SNOWDEN: 'Stress-Corrosion of Austenitic Stainless Steels in Steam and Hot-Water Systems.'
Jnl. Iron and Steel Inst., 1957, vol. 186, Aug., pp. 406–22.

Although intercrystalline corrosion of austenitic steels resulting from unsuitable heat-treatment or from the heating involved in welding is no longer a serious problem, transgranular stress-corrosion is still difficult to combat by metallurgical means. Moreover, some uncertainty exists with regard to the exact nature of the effect, and the extent to which stress-corrosion failure occurs in service. References in the literature to such failures are infrequent, and practically all the laboratory tests have been confined to experiments in boiling chloride solutions, i.e., conditions intentionally designed to produce cracking and not representative of those normally encountered.

Service failures which have been examined in the laboratory with which the authors are associated have demonstrated that such failure is not restricted to materials which have been in contact with chloride solutions, but may occur in steam and heat-exchanger equipment handling relatively pure water and steam. The International Nickel Company has reported similar experience (see *Corrosion*, 1957, vol. 13, pp. 397t–404t; *Nickel Bulletin*, 1957, vol. 30, No. 9, p. 174), and other laboratory work in the U.S.A. has shown that cracking can occur when very little, if any, contamination is present. It is, however, known that stainless steels have in many cases given very satisfactory service in steam and hot-water systems, and it may reasonably be concluded

that the conditions necessary for the occurrence of stress-corrosion occur only infrequently in practice.

In view of the likelihood of the increasing use of austenitic stainless steels in plant handling high-temperature water and steam, further investigations have been carried out, to establish the conditions most likely to lead to cracking.

The work was done in three sections, covering, respectively, tests in (1) 'live' steam from a works boiler, (2) high-pressure stationary steam, and (3) a high-pressure circulating hot-water system. The apparatus used for the respective series of tests is described in some detail, with illustrations.

Some tests were made on specimens of 18-12 chromium-nickel steel, but for most of the experiments a lower-nickel steel of the '18-8' grade was used, since it is known that less-highly-alloyed steel is somewhat more prone to cracking of the type under investigation, and in these experiments the maximum degree of susceptibility was to be preferred. The tests were planned to study the effect of various contaminants in the fluids handled, the range of pressures and temperatures at which stress-corrosion occurs, and the effect of oxygen in the fluids. The applied stress was also varied in some of the tests.

From the comprehensive observations made the authors deduce the following general conclusions:

'The evidence so far obtained indicates that this type of cracking occurs only under pressure and temperature conditions which are consistent with the presence of a film of electrolyte on the steel surface, and only if certain impurities, such as chloride and caustic, are also present.

'In highly superheated steam, such as 600°C. and 1500 p.s.i., no stress-corrosion has been found. Provided the steel surface is clean, ordinary creep data should be applicable in steam, but premature failures are likely with steel contaminated with chlorides, due to an oxidation effect. This effect is more important in air than in steam and is presumably not confined to austenitic steels.

'At lower temperatures, and particularly below about 400°C., stress-corrosion can occur with certain substances such as chlorides and caustic. As far as could be ascertained, no stress-corrosion occurs under really pure steam conditions.

'The cracking with chloride contamination is rapid only near the dew point and it is slow at 20°C. superheat. At much higher superheat values it may not occur. With caustic contamination there is cracking even at high superheat values.

'Oxygen seems to be necessary for chloride cracking, but not for caustic cracking.

'Contamination of the steel with chlorides or caustic may occur on evaporating surfaces and, in particular, in restricted spaces where concentration of impurities takes place. Carry-over of impure water from boilers is also a possible source of contamination. The presence of soluble impurities in the steam is considered less likely in practice, but not impossible.

'Under really bad conditions all the austenitic steels are considered to be susceptible to stress-corrosion. Under borderline conditions the 12 per cent. nickel type may offer a slight advantage, but further work (not fully described in this paper) has shown that even an 18 per cent. nickel nickel-chromium steel is not fully resistant to cracking. At 30 per cent. nickel there is a considerable improvement in resistance. The appearance of the stress-corrosion cracks, in conditions of both caustic and chloride contamination, is generally similar to that previously found on specimens exposed to boiling chloride solutions. In slightly superheated steam the cracking is associated with a distinctive type of corrosion, which is described in the paper.

'It has also been found that if the steel is contaminated with wet chlorides stress-corrosion cracking is possible at elevated temperatures in high-pressure air (and presumably also in other oxygen-containing gases).'

Influence of Irradiation on Resistance of Stainless Steel to High-Temperature Water

G. E. GALONIAN, E. J. CALLAHAN and R. F. KOENIG: 'Effect of Radiation on the Corrosion of Metallic Materials in 580°F. Water.'
U.S. Atomic Energy Commission, Knolls Atomic Power Laby. Report KAPL-M-GEG-4, Nov. 11, 1955; 20 pp.

Results of tests made, over a period of three months, under dynamic conditions, both in-pile and out-of-pile.

Of the materials tested, the austenitic stainless types were the most resistant to corrosion. Hafnium and Zircaloy 2 were slightly less resistant; these materials formed an adherent scale, and they were not affected by pile radiation. The material showing poorest resistance to corrosion was carbon steel, but in this instance also irradiation did not appear to affect the degree of attack. Corrosion-resistance of the steels tested increased with rise in chromium content: in this group of materials irradiation appeared to accelerate corrosion.

Carbide Precipitation in Extra-Low-Carbon Nickel-Chromium Stainless Steel

R. O. STEINER and P. S. TROZZO: 'Grain-Boundary Carbides in Extra-Low-Carbon Stainless.'
Metal Progress, 1957, vol. 72, July, pp. 108-10.

Following a brief résumé of the three main methods which have been adopted to prevent intergranular corrosion in austenitic steels, the authors draw attention to the fact that although the extra-low-carbon 18-8 steels are immune from breakdown in many types of service, intergranular corrosion has been observed in steels of even lower carbon content than the 0·03 per cent. max. laid down, for example, for the 304-L type.

This paper summarizes results of a study of the microstructure of a steel of that grade, which had

been sensitized by heating for two hours at 1250°F. (675°C.) and water-quenched. The material was of the following composition:

chromium 18·32, nickel 10·32, carbon 0·016, manganese 1·68, silicon 0·50, phosphorus 0·019, sulphur 0·019, per cent.

Following the observation, at the mill, of an intergranular network which was assumed to be carbide, the steel was examined in the laboratories of U.S. Steel Corporation, by electron-diffraction techniques.

It was found that the carbides which precipitated in the grain boundaries had the composition $M_{23}C_6$, though it was not possible to determine how many of the metallic atoms were iron and how many were chromium. Associated with the carbide precipitate a narrow, rapid-etching zone was observed along the grain boundaries. The authors consider it reasonable to assume that such zones are identical with the regions which, in sensitized steel, are susceptible to intergranular corrosion. Since there was a pronounced precipitation of complex carbide particles along grain boundaries, the grain-boundary region had a lower chromium and carbon content than the bulk of the grain. Depletion in these two elements favours formation of low-chromium ferrite when the austenite cools from the sensitizing heat. The very sharp outline of the rapid-etching zone also gave the impression of a phase boundary rather than a parting limit or passivity limit. The amount of carbon precipitated in the grain-boundary region appeared to be considerably higher than that originally present, and it therefore appeared that much of the carbon must have diffused from the bulk of the grain to the grain-boundary region during the 2-hour heating at 1250°F. (675°C.), a temperature at which the diffusion rate of carbon is known to be relatively high.

Inhibition of Nitric-Acid Attack on Stainless Steel

W. L. WALKER: 'Inhibition of Nitric-Acid Corrosion of Stainless Steel.'
U.S. Atomic Energy Commission, General Electric Co. Report H.W. 42100, May 1, 1956; 9 pp.

The experiments reported were carried out to test the validity of the assumption that an appreciable proportion of the corrosion attack undergone by stainless steels in contact with nitric acid is due to the presence of some of the lower oxides of nitrogen, NO, NO_2, etc., and that if such oxides could be eliminated from process solutions the life of chemical equipment might be lengthened, for example in acid fractionators. Tests on sensitized extra-low-carbon 18-8 chromium-nickel steel in 65 per cent. nitric-acid solution at elevated temperature, for 48-hour periods, showed that the addition of urea, in concentrations of 0·1*M* and 0·2*M*, effects substantial reduction in corrosion. No substantial benefit is derived from smaller concentrations of urea or by sparging with air, oxygen or an inert gas.

Corrosion of Stainless Steel in Contaminated Nitric-Acid Pickling Solution

R. S. PEOPLES, F. W. FINK, O. M. STEWART and W. J. BRAUN: 'Corrosion of Type 347 Stainless Steel in the Uranium-Derby Pickle Bath.'
U.S. Atomic Energy Commission, Battelle Memorial Institute Report B.M.I. 927, July 14, 1954 (recently declassified); 26 pp.

In production of uranium, uranium fluoride is reduced by magnesium, and the resulting metal ingot (derby) has a residual scale of calcined magnesium fluoride, which is removed by immersion of the ingot in a 45 per cent. nitric-acid solution, contained in nickel-chromium stainless-steel tanks. The pickle is maintained at temperatures varying between 170° and 232°F. (77° and 110°C.). The increase in concentration of fluoride ion resulting from removal of the scale has been found to cause corrosion of the steel tanks; at a level of 0·3 g./L or above the attack becomes excessive.

With a view to determining the possibility of reducing the corrosion by complexing the fluoride ions with selected metal-ion additions, screening tests were made with simulated pickle solutions containing additions of aluminium, iron, cobalt, nickel, molybdenum and vanadium. Aluminium or ferric ions were found to be effective; aluminium was the more beneficial.

In solutions at 170°F. (77°C.) the addition of 2 g. of aluminium ion per gram of fluoride ion reduced the attack on the stainless steel to less than 2 mils per month. Tests in solutions operated at 185°, 210°, and 232°F. (85°, 100° and 110°C.) indicated that, for given fluoride-ion concentrations, corrosion increased with rise of temperature, and that correspondingly large amounts of aluminium were required to confer equivalent protection.

The mechanism of the protective effect of aluminium is explained by the well-known tendency of aluminium to form a complex with fluoride ions. There is evidence that the complex is in the form of $[AlF_6]^{\equiv}$ By thus reducing the number of free-fluoride ions in solution, the corrosiveness of the pickle is reduced. The protective effect was found to operate in such pickling solutions in both the presence and absence of uranium.

Resistance of Stainless Steels to Oxalic Acid

W. L. WALKER: 'Corrosion of Types 304-L and 347 Stainless Steel by Oxalic Acid.'
U.S. Atomic Energy Commission Report H.W. 40804, May 14, 1956; 9 pp.

The aim of the work reported was to provide data indicating the suitability of oxalic-acid solutions as cleaning media for stainless steels, and to forecast the probable behaviour of stainless steels in chemical plant handling oxalic-acid-base mixtures.

The tests were made on specimens of extra-low-carbon 18-8 chromium-nickel steel of the 304-L type, on niobium-stabilized steel of the 347 type (chromium 17-19, nickel 9-12 per cent.), and on

titanium. Both the steels were exposed in the sensitized condition. The solution used was 10 wt. per cent. of oxalic acid, at temperatures of 25°–100°C. For the steels, test periods were 0·5, 1, 2, 4, 8 and 24 hours; for titanium, exposure times were extended to 100 hours.

The results indicate that a solution of the type employed in the tests, when used at temperatures of 80°–100°C., appears, from the corrosion standpoint, to be a satisfactory repetitive cleaning agent for stainless-steel process equipment: corrosion rate was of the order of 0·006–0·020 i.p.m. At temperatures above 35°C. oxalic acid in any concentration is unsuitable for repetitive cleaning of titanium.

Sulphide-Corrosion Cracking: Mechanism and Characteristics

A. E. SCHUETZ and W. D. ROBERTSON: 'Hydrogen Absorption, Embrittlement and Fracture of Steel.' *Nat. Assocn. Corrosion Engineers, Publn.* 57–17. *Corrosion*, 1957, vol. 13, July, pp. 437t–58t.

Spontaneous failure of steel in corrosive media containing hydrogen sulphide is a problem which has recently assumed serious proportions in the petroleum industry, since a failure of tubing in high-pressure sour gas-condensate wells can result in the loss of the well, and possibly other associated damage. Reports contributed to a symposium on sulphide stress-corrosion held in 1952 (*ibid.*, vol. 8, pp. 326–60) contained results of laboratory and field investigations by a number of the operating companies in the U.S.A., and revealed the complexity of the problem. The theories on mode of failure then proposed were numerous, and, since development of effective remedial measures depends to an important extent on a more intimate knowledge of the causes and the mechanism of cracking, the National Association of Corrosion Engineers sponsored further research. The project was made possible by an initial grant from The International Nickel Company, Inc., and was supported by twenty other companies. The present report comprises a summary of data assembled during the research, and conclusions drawn from them.

As a background to the experimental work, information available in the literature concerning sulphide-corrosion cracking was reviewed. The survey revealed lack of agreement as to whether failure is due primarily to hydrogen absorbed from the corrosive media involved or whether it is the result of structural corrosion and associated cracking. One of the objects of the research was to investigate these conflicting theories, and a further aim was to determine the possible influence of composition and structure of steels on susceptibility to stress-corrosion cracking in the conditions involved in oil-well service.

The work described was carried out on a series of relatively pure iron-nickel alloys, chosen because the iron-nickel system is the simplest one which exhibits the phenomena of sulphide stress-corrosion and is also unique in that all three structures characteristic of ferrous materials can be obtained with a minimum of compositions. The whole series of materials tested covered four carbon steels (carbon 0·023–0·37 per cent.) and four low-carbon nickel-iron alloys representative, respectively, of 5, 10 and 30 per cent. types.

The criteria of embrittlement used in this investigation were as follows: (1) change in ductility as measured by a bend test; (2) effect of hydrogen on the yield point; (3) recovery of ductility with time, after exposure to embrittling conditions.

The scope of the four sections of the investigation are shown below:

(1) Comparison of hydrogen-sulphide embrittlement with that caused by cathodic charging of hydrogen from dilute sulphuric-acid solution. Investigation was made of spontaneous fracture under conditions of constant deformation, as dependent on the composition of the alloys, the heat-treatment and the degree of plastic deformation which they had undergone, and the chemical environment.

(2) Quantitative measurement was made of hydrogen absorbed by iron-nickel alloys from aqueous hydrogen-sulphide solutions, as dependent on time, composition of the alloys, and their structure. Determinations were also made of absorption of hydrogen cathodically discharged from sulphuric acid, as influenced by composition and structure of the alloys, and by the chemical variables associated with the discharge process.

(3) Permeation of hydrogen through iron-nickel alloys was studied as a function of structure (austenite, martensite and ferrite).

(4) Time-dependence (delayed fracture) was studied as influenced by applied stress, structure of the alloys, and their hydrogen concentration.

The authors give the following condensed summary of the main findings:

'The basic cause of failure is absorption of hydrogen. The principal factors in service failure are internal stress, the magnitude of the applied stress and the hydrogen content of the material. When the level of stress and the hydrogen content are sufficiently high, steel of both martensitic and ferritic structure can fail under operating conditions. Trace amounts of carbon, oxygen and nitrogen in a 10 per cent. nickel-iron alloy had no detectable effect on failure by embrittlement and cracking.

'Adoption of the limiting strength or hardness of a steel below which fracture does not occur in constant-deformation tests is unreliable as a criterion for predicting service life; the remaining alternative for prevention of failure is, therefore, reduction of the hydrogen content of the steel.'

Chromium: A.C.S. Monograph

See abstract on p. 180.

Nickel-Chromium-base Filler Wire for Welding

SOC. AUTOMOTIVE ENGINEERS: 'Alloy Wire, Corrosion- and Heat-Resistant.'
A.M.S. Specification 5778, Jan. 7, 1957.

The specification lays down standards with regard to condition, quality, and dimensions of material for use as bare-wire filler metal for inert-gas metal and tungsten-arc welding. The percentage composition limits are: carbon 0·08 max., manganese 1·0 max., silicon 0·50 max., sulphur 0·01 max., chromium 14·0–17·0, nickel+cobalt 70·0 min., cobalt (if determined) 1·0 max., niobium+tantalum 0·7–1·2, titanium 2·25–2·75, aluminium 0·40–1·0, iron 5·0–9·0, copper 0·50 max., other impurities total 1·0.

Sigma Embrittlement of Austenitic Steels in Welding

A. HOERL and T. J. MOORE: 'The Welding of Type 347 Steels. Statistical Analysis of Effects of Various Elements on the Crack Sensitivity of Fully Austenitic Type 347 Welds.'
U.S. Atomic Energy Commission Publn. NYO-3500, Oct. 29, 1956; 26 pp.

The use of electrodes which deposit weld metal of 4–8 per cent. ferrite content, although minimizing susceptibility to cracking, involves some risk of embrittlement, due to formation of sigma phase. Much effort is therefore being directed towards development of a crack-resistant fully-austenitic weld metal. The authors refer to previous experiments which have indicated that in weld metal which is fully austenitic at room temperature cracking is influenced by composition, within the normal limits of 18-8-Nb steels. Further work, reported in this paper, was carried out to develop, by statistical interpretation of the effect of varying elements, a formula which can be used to predict degree of crack-sensitivity in austenitic weld metal, and thus ultimately lead to control or elimination of cracking. No ferrite was present in any of the weld-metal compositions tested.

All the electrodes used were prepared with a standard lime-type coating containing no titania, and, to avoid a possible variable due to plate heat-treatment, all the parent plates were heated to 1950°F. (1065°C.) for half an hour and water-quenched. A sensitive segmented circular-groove cracking test (fully described) was used to evaluate the weld metals, in the as-deposited condition.

Elements intentionally varied, by additions to the coating of the core wires, were carbon, manganese, silicon, sulphur and phosphorus, and incidental slight variations occurred also in the contents of chromium, nickel, niobium+tantalum, and nitrogen. The experimental results, combined with statistical treatment of the observations made, lead to the following conclusions with regard to influence of composition of fully austenitic deposits on susceptibility to cracking in the as-deposited condition. (Cracking due to, or during, heat-treatment, was not investigated.)

Carbon and *manganese* are potent inhibitors of cracking. ***Phosphorus*** was the most powerful crack promoter, and ***sulphur*** also induced increased tendency to cracking. Since the range of these four elements was varied over relatively wide limits, such conclusions are considered to be well supported. ***Silicon*** (previously reported to be a major factor in promoting cracking in austenitic deposits) was also varied over an appreciable range, but increasing amounts caused only slight increase in cracking.

The *chromium* range was only narrow, but, within the unintentional variations occurring, increase had a slightly beneficial influence. Variation in *nickel* was also small; the statistical method employed in this investigation indicated that increasing amounts tend to promote cracking, but the authors consider that this conclusion should not be accepted as fact until a wider range of nickel content has been covered. Statistics revealed *niobium* as a mild crack inhibitor, within the relatively high range involved (0·65–1·05 per cent.), but no information was obtained on its influence in a lower range. *Nitrogen*, present in only residual amounts, has apparently a strongly inhibiting influence, but in view of the small amounts involved, this finding must be tentative.

The authors believe that the test data and the statistically derived relationships have advanced the possibility of control of cracking by adjustment of composition.

Self-Fluxing Brazing Alloys containing Nickel

N. BREDZS and H. SCHWARTZBART: 'Self-Fluxing Airproof Brazing Alloys.'
Welding Jnl., 1957, vol. 36, July, pp. 348S–52S.

This paper presents a progress report on some of the work done under an extensive programme of research sponsored by Armour Research Foundation. The term 'self-fluxing, airproof' is defined as signifiying 'alloys which can be used for brazing in air without any additional fluxes or protective atmospheres'. The word 'additional' is added to the definition to differentiate external fluxes from fluxes which are formed *in situ* as a result of the reduction reactions occurring between components of the filler metal and the oxides on the surface of the base metal.

The main object of the paper is to consider the latest progress in the theoretical approach which has proved successful in developing compositions suitable for such use. Some of the experimental results are also detailed, and a typical self-fluxing airproof brazing alloy is described, but certain details are still withheld in view of pending patent applications.

The work done has shown that it is possible to produce a self-fluxing airproof brazing alloy by adding another highly-reducing element to an alloy which already contains lithium. The addition element must have the same high affinity for oxygen at brazing temperatures as is characteristic of lithium. The most important pre-requisite for obtaining airproof brazing properties is that the binary phase diagram of the two oxides (the lithium oxide and the oxide of the other highly-reducing element)

shall have at least one eutectic point which has a melting point considerably below that of the solidus temperature of the brazing alloy in question.

The use of lithium+boron is almost ideal for this purpose because: (1) both lithium and boron have high affinity for oxygen at brazing temperatures; (2) according to the binary phase diagram, Li_2O–B_2O_3, the two oxides form a series of low-melting compounds and mixtures of compounds; (3) lithium borates have excellent fluxing properties.

Experiments with brazing alloys made up on the basis of these considerations have proved the correctness of the approach. A copper-nickel-lithium-boron alloy (76·2-18·3-4·75-0·75, per cent.) has been used to braze steels in air without fluxes and without the use of any protective atmosphere. Although this particular alloy is not suitable for commercial use, on account of its poor corrosion-resistance and a tendency towards segregation, its ability to give self-fluxing airproof brazing material demonstrates the validity of the principles outlined above. Both the difficulties referred to arise from the complete insolubility of lithium in solid nickel or copper, and an effort is being made to develop alloys which will be capable of dissolving both lithium and boron, and hence be likely to prove commercially useful.

Brazing of Beryllium to Nickel-base High-Temperature Alloys

K. G. WIKLE and R. MAGALSKI: 'Brazing Beryllium Tubing to High-Temperature Alloy Collars.'
U.S. Atomic Energy Commission Report ***COO***-310, June 1956; 22 pp.

The report describes a method for vacuum-furnace brazing beryllium tubing of about 4-in. o.d. × 0·060-0·100-in. wall thickness into collars of precipitation-hardening stainless steel (17-7 P.H.), high-chromium steel, Inconel X (precipitation-hardening nickel-chromium-base alloy) and Hastelloy X (nickel-chromium-cobalt-base alloy containing molybdenum, tungsten and boron).

A eutectic 72-28 per cent. silver-copper brazing alloy is placed between cleaned joint surfaces, a small mechanical pressure is imposed on the joint, and it is heated to about 1470°F. (800°C.). At 750°F. (400°C.) the joints so produced have a shear strength up to 7,000-8,000 p.s.i.

Welding of Stainless Steel in Atomic Energy Plant

E. B. LAVELLE, L. H. RASMUSSEN and E. M. KUCHERA: 'Developments in Stainless-Steel Welding in the Nuclear Programme.'
Industrial Atom Monograph; 19 pp.
Published by *Technical Information Service, U.S. Atomic Energy Commission, Washington* 25, *D.C., U.S.A.*

The high quality required in chemical plant used in atomic-energy installations emphasizes the need for welds of extra-high quality: techniques for production of high-grade joints are therefore receiving constant attention. This monograph (which describes a method developed by Hanford Atomic Products Operation) opens with a photograph illustrating the complexity of the piping systems found in such plant, in which, due to the radioactive conditions obtaining in service, no maintenance is possible.

The characteristic features of techniques which are being used for root-pass welds in butt joints with the inert arc are reviewed, with notes on their limitations. The five groups are:

Bevelled open-joint.

Consumable-insert bevelled or U-grooved.

Closed-joint bevelled or U-grooved.

Closed-joint bevelled or U-grooved, with edge rolled down.

Closed-joint with abutting edges specially machined to provide additional filler metal to the weld puddle.

It is noted that one unsatisfactory feature inherent in all the closed joints welded without filler metal is that closure-pass welds are susceptible to centreline cracking, due, possibly, to production of a fully austenitic weld bead deriving from the composition of the basis metal. Only the bevelled open-joint welded with filler material, or the consumable-insert joints, can be made with ferrite-controlled compositions.

One of the advantages of the method described in this monograph is that a controlled amount of ferrite can be introduced into the weld area, and the outstanding feature is that satisfactory uniformity of the inner weld surface can be obtained with comparative ease. The main characteristics of the process are:

Purging is carried out with argon.

The joint is tacked securely, at a spacing slightly less than the diameter of the filler rod which is to be used.

The filler rod is held down solidly into the joint root and tangent to the pipe at that point.

The arc is concentrated on the end of the filler rod, at the point at which it is held tightly against the root of the joint.

The arc is held as short as possible (preferably $\frac{1}{32}$in.).

The arc is traversed along the joint to form the root-closure weld.

Full details of procedure are given in the monograph, with informative illustrations, and the interior of a typical completed pipe weld is shown.

Facing of Press Shafts with Chromium-Nickel Steel

J. A. RAU: 'Surfacing with Stainless Prevents Pit Corrosion.'
Iron Age, 1957, vol. 180, July 18, pp. 1120-1.

The article describes a hard-surfacing technique by which the carbon-steel shafts and rams of 4,000-ton hydraulic extrusion presses were re-conditioned after pitting corrosion had occurred. The presses are used to hot-form aluminium alloys, and the pitting, which developed principally when the equip-

ment was idle, was believed to have been accelerated by the lubricant used. The corrosion had the effect of preventing maintenance of a tight seal where the shafts entered the stuffing boxes, and had interfered with effective lubrication.

The technique developed to overcome this problem makes use of automatic submerged-arc welding equipment to deposit a coating of 18-8 chromium-nickel stainless steel on the surface of the shafts. The welding machine is mounted on the arm of a heavy post drill-press stand, which in turn rides on the cross carriage of a large, heavy-duty lathe. The shaft turns slowly at constant speed and the automatic welding head lays a continuous, closely controlled bead of stainless steel along the shaft, as the carriage traverses by means of a screw feed. A special feature of the technique is that, to prevent 'popping through' of the arc, a special agglomerated flux, directed from both front and back, flows over the work

The result is a continuous, tightly packed spiral of deposited stainless steel, having an overlap and characterized by uniformity of shape which, it is claimed, can be achieved in no other way. After machining and straightening, the shafts are ground to a near-mirror finish.

The length of built-up area varies from 4 in. to 10 ft. and shaft diameters are $6\frac{1}{2}$ to 15 in.

Shafts restored in this way have been in service for more than a year, with no sign of defects, and the technique has proved so successful that new shafts are now being surfaced with stainless steel before being placed in service.

Welding of Nickel and High-Nickel Alloys

See abstract on p. 180.

Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Registered Trade Marks.*

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